Industrial Production and Delivery of 670 Fundamental Power Couplers for the XFEL Linac

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INDUSTRIAL PRODUCTION AND DELIVERY OF 670 FUNDAMENTAL POWER COUPLERS FOR THE XFEL LINAC*

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Abstract

Within the XFEL project, Laboratoire de l'Accélérateur Linéaire (LAL) is engaged to deliver 670 fundamental power couplers operating at 1.3 GHz at nominal power of 120 kW for the superconducting linac. This paper presents the strategies chosen for industrial production along with that of conditioning so as to deliver couplers at the rate of 8 per week.

INTRODUCTION

The XFEL fundamental power couplers (FPC) are based on the TTF3 FPC design [1]. Three major design changes were made after the pre-industrial study performed with several industrial partners:

- Additional reinforcements around the bellows.
- Suppression of photo-multiplier and infrared diagnostics.
- Use of an actuator for antenna adjustment.

Table 1: XFEL FPC main parameters

Frequency	1.3 GHz
Operation	pulsed (720µs filling time; 600µs at 5mA beam)
Peak Power (+ control margin 27%)	≤ 150 kW (cavity gradient of 23.6 MV/m)
Repetition rate	10 Hz
Coupling (Qext)	$2 \times 10^6 \rightarrow 2 \times 10^7$
Two ceramic windows	safe operation / clean cavity assembly for high gradient
Maximum heat losses	0.06W at 2K; 0.5W at 4K; 6W at 70K
Insulated inner conductor	bias voltage, suppressing multipacting
Diagnostics	sufficient for safe operation and monitoring

Responsibilities of LAL within the DESY-XFEL partnership are the following:

- Writing/publication of the Call For Tender for coupler manufacture.
- Selection of the suitable candidate and contract management (quality, planning, finances).
- Daily inspections and technical performance at the manufacturing site.
- RF performances at LAL and final technical acceptance sheet.
- Dismounting and transport to the FPC integration on cryomodule site (IRFU Saclay France).

INDUSTRIALIZATION

Up scaling coupler manufacture to an industrial level is not merely a matter of producing a number of FPC of an order of magnitude higher than what has been done so far. It requires costs reduction trough effectiveness of the overall manufacturing process. Limited time frame imposes production rationalization, ordering correctly sequences and process, in order to achieve efficiency (total quality achieved with less means). Major aspects of going to industrial production of FPC are summarized in table 2.

Table 2: FPC production in comparison

	TTF3 – FLASH	XFEL
Main objectives	R&D – test	Product & process quality (reliability & efficiency)
Infrastructure	"patchwork" RF station, nominal power 1 MW	New "turn key" RF station, nominal power 4 MW
Conditioning rate	2002-2010: 90 couplers	2011-2013: 670 couplers
Production constraints	constraint only on product quality, whatever time needed	production rate of 4 pairs / week => constraints on time & quality process and resource optimization
Conditioning method	Batches of 1 pair (2 pairs in series) manual/automatic	Batches of 2 (up to 4) pairs in parallel fully automatic
Conditioning time limit	None	48 h
Data analysis	Manual a posteriori (tedious!)	Automatic on line

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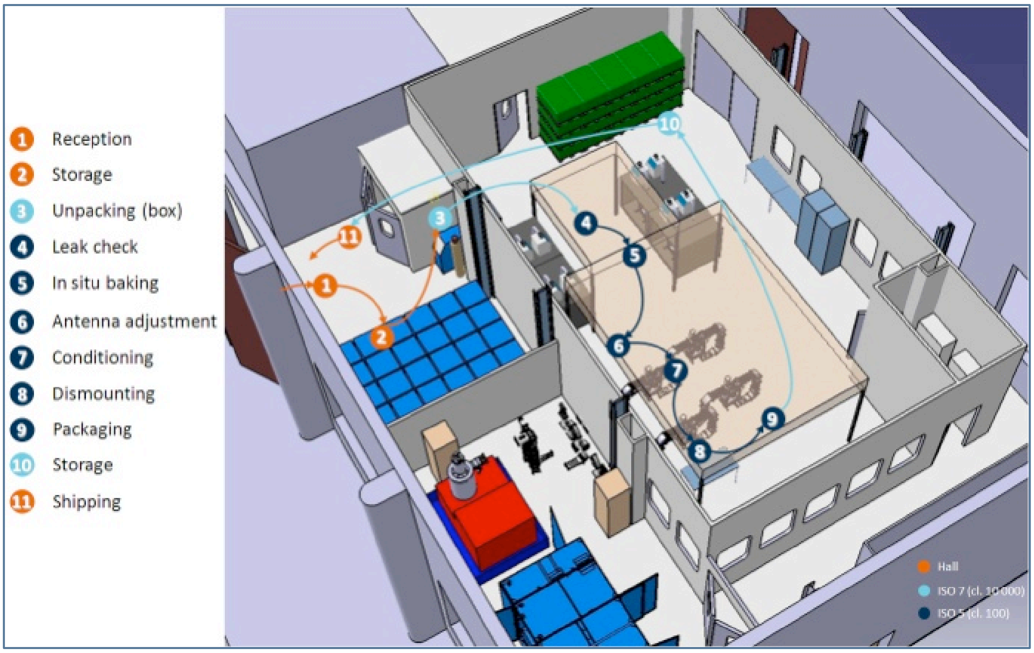

Figure 1: Complete process for RF conditioning of XFEL FPC at LAL.

Because of the FPC cost and the high risk of failure of the process, LAL has to focus on production supervision and full traceability throughout both the manufacturing and RF conditioning process. This is one of the major aspects for the industrialization of FPC delivery. That is why an inspector is appointed by the LAL at the manufacturing site and in return the manufacturer may appoint one at LAL so as to supervise the complete process, ensuring traceability of operations, industrial means used and personnel, at both the manufacturing site and at LAL.

KNOWLEDGE TRANSFER

Thus far the FPC fabrication performed by the industry included stages such as material procurement, forming, machining, degreasing, H2 out gassing, welding, brazing of subassemblies and coating of Cu and TiN layers. With this contract, additional manufacturing stages are demanded: visual inspection, cleaning and assembly onto the RF test stand and performing the leak tests. In particular coupler cleaning and assembly onto the RF test stand as a pair, are essential for performing the most efficient RF conditioning.

To ensure the accurate realization of these stages by the chosen company, a demonstration was performed during the call for tender, which gave way to video and paper documents allowing the candidates to define their own protocol for these procedures. Also, the chosen company will benefit from the training on 2 pairs of TTF3 FPC by the experts from LAL. These experts will be available for further assistance at the demand of the manufacturer.

RF CONDITIONING PROCESS AT LAL

RF conditioning infrastructure

RF conditioning at LAL was performed so far with an infrastructure containing an unreliable RF station and under semi-clean conditions, requiring personnel to take many unnecessary time consuming precautions. As a consequence LAL has to build a brand new conditioning infrastructure so that it can ensure the cleanliness, repeatability and reproducibility of the process. To reduce the risks of the RF conditioning process (dust, disoperation, damaging the coupler…), the new infrastructure has to be ergonomic and to have enough means to ensure the high rate of coupler conditioning (4 pairs a week). The infrastructure is designed in the kaizen spirit (lean manufacturing), and we focus on reliability and maintenance, to reduce non productive time (reducing the MTTR, and increasing the MTBF).

The infrastructure consists of a clean room (ISO 5 and ISO 7 standards), a storage area and the RF station delivering an electromagnetic wave of up to 5 MW power at 4 Hz and maximum pulse length of 1.3 ms.

Process at LAL

FPC are to arrive to LAL assembled as a pair on their RF test stand. As such they can spend up to 1 month in the storage area. They are unpacked from the boxes at the entrance of the clean room and from the protective bags inside the clean room under the laminar flow. Leak tests include not only the verification of the leak capacity of all joints, but also the state of the 3 volumes of the coupler pair (2 warm part enclosed volumes and the volume enclosed by the 2 cold parts and the transition cavity).

The in-situ baking lasts 72h at 130°C and can be performed on 8 pairs simultaneously. The S parameters' measurement allows the adjustment of the antenna so as to achieve the highest possible transmission rate of the RF wave. Thus prepared couplers are mounted on the conditioning lines. After conditioning the warm parts are dismounted and sent to IRFU Saclay separately from the cold assemblies. The implantation of this procedure is detailed in figure 1.

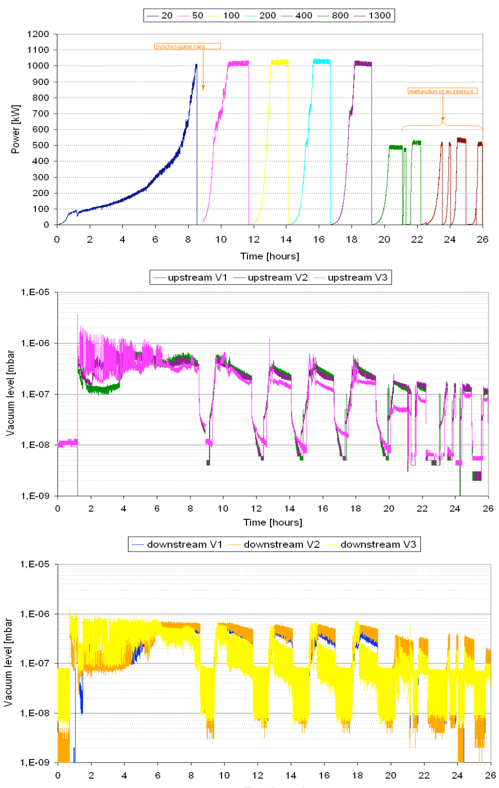

Figure 2: RF conditioning results for 2 pairs of TTF3 FPC conditioned in series.

RF conditioning procedure

The conditioning procedure consists of 7 stages defined by the pulsed length (from 20µs to 1.3ms) and the maximum power going to 1MW for the first 5 stages and 500kW for the last two. The power increase is controlled only according to the vacuum level, with interlock safety based on electronic activity inside the enclosed volumes, arc occurrence, reflected power level, ceramic temperature and vacuum level.

The capacity to condition several pairs with the same RF source was tested by conditioning two pairs in series. An example of results from this conditioning is given in fig.2. No major problems were observed.

RF test acceptance criteria

The RF conditioning of the XFEL couplers will undergo the following procedure:

1. Room temperature, travel wave conditioning, described here before.
2. Off resonance, standing wave conditioning with the couplers mounted onto the cryomodule with the same procedure as for the room temperature conditioning.
3. On resonance, standing wave conditioning with specific gradual conditioning obtaining the desired pulse structure.

Only the first stage is performed at LAL, the two other ones are done at DESY. The acceptance criteria must be decided upon the first conditioning stage alone. These criteria are summarized in table 3.

Table 3: FPC production in comparison

Stages	**Acceptance conditions**
Reception	Presence of the traveller table, data in the electronic data base; Absence of damages du to transport
Leak tests	Vacuum level in the cold part of the order of 10^{-4} mbar ; He gas leak flow of 10^{-10} mbar.L^{-1}.s^{-1} for both the warm parts and the cold assembly, for all seals, brazed and welded joints
In-situ baking	Vacuum level ≤ 10^{-7} mbar at 130°C after 72h backing ; RGA specter constraints
S parameters	S11 & S22 ≤ -30 dB S21 & S12 ≥ -0.3 dB
Vacuum level	Under 10^{-7} mbar at the end of conditioning procedure for all 3 volumes
Conditioning time	Reach 300 kW of the first conditioning stage (20 µs) within 12h ; Maximum allowed time for conditioning 48h

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